Municipal Wi-Fi deployment and crowdsourced strategies

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***Abstract*—The paper analyzes the business case of a municipal Wi-Fi deployment. It aims to make a comparison between a rollout using a "crowdsourced" approach and one using a traditional single operator public private partnership (PPP). More specifically it investigates the reduction in total cost of ownership (TCO) that can be obtained by crowdsourcing the acquisition, installation, placement, maintenace and backhauling of the network's access points.**

In a crowdsourced network a community of people share their domestic broadband connection with eachother using commercially available Wi-Fi equipment. Through a captive portal the network becomes available to other users as well such as tourists, commuters, etc... This type of deployment is compared to a more traditional one where a single private or public entity places industry grade base stations throughout the municipality.

The paper computes an average cost breakdown for various municipal Wi-Fi scenarios differing in physical data rate guarantees, equipment used and rollout strategy. A model is used that was developed to calculate these costs for a hypothetical deployment throughout the city of Ghent. The analysis shows that a significant reduction in TCO can indeed be obtained and corroborates these results by applying to them a Monte-Carlo based uncertainty and sensitivity analysis.

***Index Terms*—Wi-Fi, Techno-Economics, Crowdsourcing, Municipal Wi-Fi**

I. INTRODUCTION

Municipal Wi-Fi is the idea to let a wireless network cover the municipality. Such a network is believed to benefit the municipality and its inhabitants in various ways. Universal internet access, bridging the digital divide and e-government services are amongst the cited motivations. An overview and deeper analysis can be found in [1] and [2].

Multiple value network configurations can be used to deploy such networks. These models, not seldom with an important role for the local government, differ from eachother in initiator, used technology, leading motivations and other aspects. Previous work by the author [3] identifies integrator, wholesale, public service and community models as possible configurations.

This paper focuses on a specific implementation of the community model: the "crowdsourced" Wi-Fi network. In the crowdsourced approach, also called "Wi-Fi sharing" the access network is made up of a community of people who share their domestic broadband connection with eachother using the Wi-Fi standards. They attach a wireless router to their Local Area Network (LAN) containing firmware that allows an easy setup, a universal network identifier, priority rules for the LAN, redirection to an authentication portal and other functionalities.

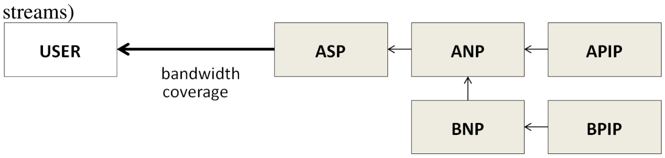
The aim of the paper is to answer the question whether or not involving its inhabitants in a crowdsourced project is a financially more attractive way of accomplishing a free municipal Wi-Fi network than relying on a more traditional public private partnership (PPP). In the latter strategy, an implementation of the public service model [3], a single operator installs industry scale outdoor base stations (BS) that are connected to the municipality's communication network.

II. APPROACH & ORGANIZATION

In order to answer the central question of this paper several separate issues have to be addressed: (1) Can crowdsourced Wi-Fi provide the same service level throughout the city as single operator Wi-Fi networks? Both in the sense of bandwidth as well as coverage. (2) Crowdsourced Wi-Fi involves various actors, can these be incentivised to join the network and can freerider behaviour be avoided? (3) Does crowdsourcing Wi-Fi in fact reduce the total cost of ownership (TCO) of the municipal wireless network? Only if these 3 conditions are met can a Wi-Fi sharing approach be realistically considered.

These conditions will be treated in the following three sections. It starts with section III which gives a general insight in the crowdsourced Wi-Fi value network. Who is involved? What rollout strategy is used? What service level can be offered by the network? This section on the value network is followed by a section (IV) explaining the viewpoint of the participating households which can be seen as the key partners involved. Why do they join? It introduces insights from existing cases. Next up is the financial analysis in section V which answers whether crowdsourced Wi-Fi not only is a feasible approach but also financially more beneficial one. It makes a comparison of different rollout strategies in light of the project's total cost of ownership and explains the data (GreenWeCan Project, cfr. Acknowledgement) that was used as well the techno-economic calculations that were made for a sample case: a rollout in the city of Ghent, the second city in the Flemish northern half of Belgium.

Fig. 1. Simplified value network for municipal Wi-Fi (arrows indicate value streams)



Two more sections follow the financial analysis. The robustness of the results is researched by means of a Monte Carlo based uncertainty and sensitivity analysis in section VI and section VII finally gives an overview of the research's main observations and conclusions.

III. The municipal Wi-Fi value network

A simplified but sufficient representation of the municipal Wi-Fi value network described in [3] is given in figure 1. It shows that a municipal Wi-Fi network requires access points, operated by the access network provider (ANP) and connected to an internet backhaul network operated by the backhaul network provider (BNP) and backhaul physical infrastructure provider (BPIP). The access points are attached to base stations throughout the city operated by the access physical infrastructure provider (APIP) and user administration (authentication, payment, etc...) is handled by the access network's service provider (ASP).

The costs incurred by the municipality and the quality of service (bandwidth and coverage) that the municipal Wi-Fi network as a whole can provide to its users is dependent on who takes up which roles in the value network. In this paper we start from three possible configurations. The first is a traditional PPP, the second and third are both subtypes of a crowdsourced Wi-Fi network (CWN). Table III summarizes the distribution of roles in these configurations.

The first configuration is the **traditional PPP**. In this configuration the municipality is anchor tenant of a Wi-Fi network deployed by a commercial network operator using industry grade base stations of the type used by cellular network operators to offload their traffic. The municipality is responsible for the backhauling and allows the network operator to place the access points on its buildings. The network operator deploys the access points and performs user authentication. This approach allows full coverage and physical datarates of 26 Mbit/s and higher with enough base stations (cfr. section V).

The second configuration is a municipal CWN independent of the bakchaul operator: the **independent CWN**. Here households share their domestic broadband connection for which they have a subscription with the incumbent. The municipality functions as ANP and ASP by funding the access points and managing user authentication services. In this approach, coverage and bandwidth are in direct relation with the amount of households participating in the network. For residential neighbourhoods this model can generate similar services to the PPP as long as a suffiently high percentage of the households is willing to participate (cfr. section V).

In the third configuration the municipality becomes a virtual network operator that offers a Wi-Fi sharing option and integrates the roles of ANP and BNP. We call this the **VNO CWN**. This approach is researched because most incumbent network providers explicitly prohibit sharing the domestic broadband connection. By becoming an operator, the municipality avoids this problem. Coverage and bandwith requirements in the VNO CWN are similar to the independent CWN.

For the second and third configuration concerns may arise for areas where there are no, or insufficient, residential dwellings such as business area's, parks, etc... These regions indeed are problematic for the crowdsourced approach as the density of the AP's drops. This is in favour of the traditional PPP. Nevertheless it is also possible to let the municipal Wi-Fi network be a hybrid: crowdsourced where possible, traditional where necessary.

IV. Convincing the household

In order for a crowdsourced Wi-Fi network to exist we thus need both, a network operator willing to invest and households willing to participate. In this paper it is the municipality that takes the role of network provider but also private parties can find motivations for taking up the joint roles of network provider and service provider: selling mobile access, selling Wi-Fi sharing devices, customer binding, etc... The question however what reasons the households have to join? We search an answer in two existing crowdsourced Wi-Fi business cases.

Worldwide the most widespread crowdsourced Wi-Fi network is the FON network. The FON business model works as follows. FON operates by selling custom made Wi-Fi sharing devices and by selling mobile internet access to non participating users. Participating users have to buy a FON-enabled access point and share their domestic internet connection. They then have two options: either they don't ask money in return for the traffic through their access point but get free access on other shared networks, or they get a fixed percentage of the revenues of their access point but don't get free access in return.

A second example is the approach some fixed accesss providers take. They automatically equip their gateways with Wi-Fi sharing enabled access points. This results in a single integrated device consisting of a modem, router and two radios: one for the public Wi-Fi and one for the wireless LAN and can be seen as the commercial variant of the VNO CWN. The users retain the option to switch off the public radio which is switched on by default. The operator includes the Wi-Fi sharing option as a selling point for its other telecommunication services. It is not the core business but can potentially be used for mobile communication offloading. In Belgium, both Belgacom [4] as well as Telenet [5] are

TABLE I

DISTRIBUTION OF ROLES IN THE THREE STUDIED VALUE NETWORK CONFIGURATIONS

	ASP	ANP	APIP	BNP	BPIP
Traditional PPP	PPP	PPP	MUN	MUN	MUN
Independent CWN	MUN	MUN	HH	INC	INC
VNO CWN	MUN	MUN	HH	INC	INC

Access Service Provider (ASP), Access Network Provider (ANP), Access Physical Infrastructure Provider (APIP), Backhaul Network Provider (BNP), Backhaul Physical Infrastructure Provider (BPIP), Public Private Partnership (PPP), Municipality (MUN), Incumbent (INC), Household (HH)

deploying such a network.

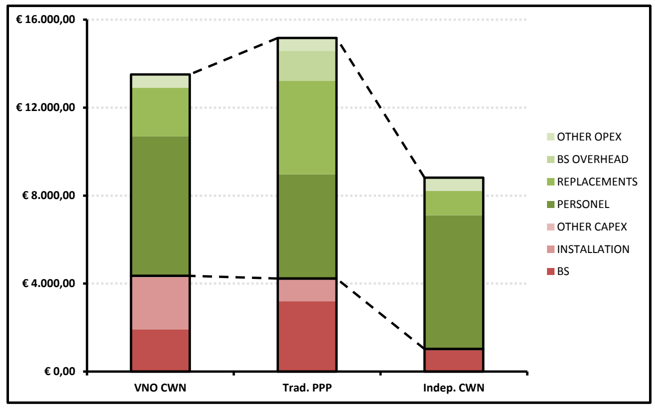
In both these cases the core incentive for the participating household is free mobile access to the network. If you don't open up your network you don't get (free) access to the public network. However, if the network operator is not a commercial party but the local government aiming to provide free Wi-Fi to inhabitants, tourists, business travellers, etc. a freerider problem emerges. If the network is already free of charge: why would you join? And even worse, if you are a small user, why would you still pay for a fixed internet subscription? This problem can be solved by imposing authentication on the network: you can only get an account if you share your domestic broadband connection. Hotels, local businesses, tourist offices also get a fixed allotment of the account pool that they can freely allocate to their visitors. This approach has as additional benefit that network connections can be identified and traced back to an individual in case any illegal content would be transmitted over the public network.

Even if an incentive can be created and the freerider problem can be avoided it still does not imply that the incentives outweigh the costs the individual household after joining the network. If an insufficient amount of households joins the network this would lead to coverage and bandwidth problems. Luckily a smart approach from the network operator's part can minimize the costs incurred by the household. The key cost in participating to a crowdsourced Wi-Fi network for a representative household is the aquisition cost of the router, a reduction in available bandwidth, depletion of traffic volume (data caps) and energy consumption. Contrary to the FON-approach and in accordance with the incumbent approach aforementioned, we propose that the local municipality finances the router. See section V for the financials. So this cost can be ignored for the user.

The reduction in available bandwidth cost can be minimized by implementing the firmware in such a fashion that the public Wi-Fi is only allocated the residual bandwidth. This means that the public Wi-Fi gets a lot of bandwidth when the home user is not using its broadband connection but the home user allways has priority over the public Wi-Fi.

With respect to energy consumption we can note that joining a Wi-Fi sharing network is for many people a replacement operation: they remove their existing Wi-Fi access point with the crowdsourced one. For those people that don't already own a Wi-Fi device the additional yearly electricity consumption can according to [6] be estimated at 25 kWh or at a price of 0.25 EUR/kWh this becomes EUR 6.75 annualy which is about 0.7% of an average household's budget.

Fig. 2. Normalized TCO comparison between the 3 scenarios for 26Mbit/s service level (EUR/km2/year)



The biggest issue however are the data caps. Many operators still limit traffic volume. Together with the fact that some domestic broadband operators explicitly disallow connection sharing the usefulness of the VNO CWN approach is shown. Not that virtual network operation is subect to market regulation which is outside of the paper's scope. Another solution would be to negotiate a remuneration for the incumbents in return for open access.

A final question might arise. Will the increase in mobile traffic backhauled through the domestic broadband networks lead to congestion on the incumbents backhaul network? This question can be countered by stating that many incumbents use their backhaul network for both their cellular and domestic network and that mobile traffic passes through it regardless. If price drops would elevate total mobile traffic, congestion may still arise and can be reduced by implementing priority rules, these however have to be in compliance with net neutrality policies.

In conclusion, an intelligent implementation would make a crowdsourced approach feasible, the question whether or not it should be prefered over a traditional PPP thus largely depends on the financial comparison of both approaches.

V. FINANCIAL COMPARISON

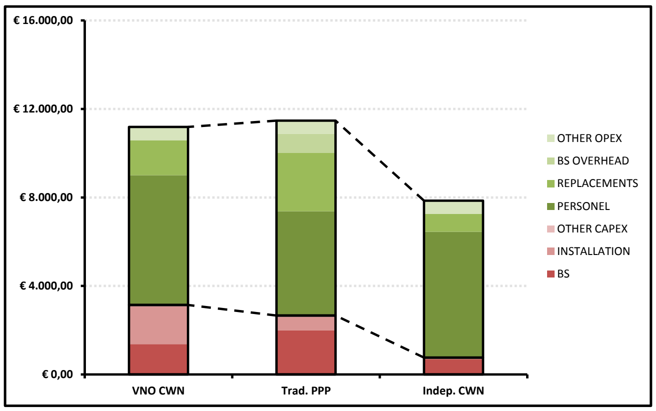
The key difference between the traditional PPP and the crowdsourced approaches in light of the project's finances for

TABLE II
COMPARISON OF EQUIPMENT AND COSTS

	Traditional PPP	Independent CWN	VNO CWN
Type	Wavion WBSn 2400 E [7]	Fonera Simple [8], [9]	Sagem Fast 4364 [10]
Energy Consumption	56 Watt	2.75 Watt	10 Watt
Overhead Cost	EUR 125 / year	EUR 0	EUR 0
BS Cost	EUR 2000	EUR 45	EUR 80
Installation Cost	EUR 600 / B.S.	PnP	EUR 90
AP/km2 (LOS)	2.5 - 4	54 - 74	63 - 68
AP/km2 (Adjusted)	10 - 16	162 - 222	189 - 266

Access Point (AP), Line of sight (LOS), Base Station (BS)

Fig. 3. Normalized TCO comparison between the 3 scenarios for 6Mbit/s service level (EUR/km2/year)



the municipality is a difference in equipment. In the traditional PPP, the municipality will subcontract a network operator that will install performant outdoor BSs on tall municipality owned buildings and connect them to the city's telecommunications network. In both crowdsourced approaches the city purchases (or develops) crowdsourced Wi-Fi enabled access points (APs) and distributes them over its population.

The specifications of the BSs explain the difference between the three approaches. The first type is performant and requires a lower density to guarantee full coverage, but is more expensive and the latter two are inexpensive APs with a smaller coverage due to a lower antenna gain and being placed indoors. In our analysis we identified three concrete devices, one for each configuration. For the traditional PPP we looked at the Wavion WBSn 2400 E, used as a high performance base station in the ZapFi [11] network in Brugge; For the independent CWN we consider the Fonera Simple which is used in the FON network and for the VNO CWN we take the Sagem 3648 that is used by Belgacom. A comparison of these devices is given in table II which contains cost, power consumption and coverage information. The latter was calculated using the Erceg C path loss model for urban environments [12], it provides converage information for two service levels: physical data rates of 6Mbit/s (left, limited mobile usage but sufficient for sensor backhauling) and 26 Mbit/s (right, normal mobile usage).

The specifications in table II are used to calculate the capital expenses (CapEx, installation and equipment) of the three network configurations. The operational expenses (OpEx) can be calculated as well. These include server rental, BS replacements, advertising, wages, office space and other personnel overhead. These are all modeled using a driver based approach with the project's user base as principal driver. The user base is calculated using sigmoid adoption forecasting functions [13] that can be estimated from user surveys.

The sum of the OpEx and CapEx posts allows the calculation of the project's discounted TCO which is calculated with a horizon of 10 years starting in 2013 and an annual discount rate of 10%. For reasons of comparison, this result is normalized to the the yearly cost to cover 1 square kilometer of urban territorium. This procedure is repeated for the various deployments and the results are visualized by figures 2 and 3, for the 26 Mbit/s and 6 Mbit/s service levels respectively.

It is clear from this figure that the TCO can be significantly reduced in the two crowdsourced Wi-Fi scenarios, reductions of 11% and 42% respectively can be obtained. Closer inspection shows that the reductions are about 50% due to OpEx and 50% due to CapEx in the independent CWN and entirely OpEx related in the VNO CWN approach. The OpEx savings are mainly explained by the replacement (equipment and intervention) costs of defective BSs as well as the overhead cost generated per BS which is estimated at EUR 150 per BS and externalized in the two crowdsourced approaches (cfr. supra). The additional CapEx reductions that occur in the independent CWN follow the absence of installation costs and lower AP prices per square kilometer. We also see that in both crowdsourced scenarios the labour costs are relatively higher than equipment costs compared to the traditional PPP which has high equipment cost despite having fewer BS per square kilometer. This importance of labour reduces the advantage of especially VNO CWN in the 6Mbit scenario in which fewer equipment is used but still a lot of installation costs have to be paid. The 6Mbit/s deployments are less costly than their 26 MBit/s counterparts but the effect is only significant for the traditional PPP model, again due to the higher importance of labour in the crowdsourced approaches.

The difference between the independent CWN and VNO CWN cases can be sufficiently explained by a difference in equipment and installation costs, the integrated devices are more expensive as they include an AP as well as a modem and are not entirely plug and play: an installation by a technician is required in case of a new broadband subscription.

These results prompt the conclusion that it is financially preferable for the municipality to opt for the crowdsourced Wi-Fi strategy which is probably a hybrid form between the independent and VNO CWN approach. This conclusion holds even if the network operator can use an existing municipal backhaul connection and the Wi-Fi sharing BSs have to be financed by the local municipality.

VI. Robustness

In this section the consequences of input uncertainty are analyzed. Does the conclusion that crowdsourcing is a viable strategy still hold if the parameter values are not what they are estimated to be? What source of uncertainty has the biggest impact? An answer to these two questions is searched using uncertainty and sensitivity analyses respectively. Both the analyses are performed in Monte Carlo based experiments in which uncertainty is added to some of the model's parameters by means of a joint probability distribution from which 10000 repeated samples are drawn.

A first notable variable for which uncertainty is added is the range that can be covered by an individual BS for which our estimate is only an approximation, as path loss models fail to take into account certain specificities of the urban terrain and environment such as the placement of buildings, trees and other factors that could obstruct line of sight and signal propagation.

A second important source of uncertainty is found in the adoption related data which influences the TCO through a driver based costing approach. Adoption parameters are not trivially forecasted and in the presented research values are obtained from the literature [14] but even if cumulative timed intent data is available and the method from [15] is used, the predictions are not exact.

The next set of variables for which uncertainty is introduced are the component costs and prices. The NPV analysis makes use of price quotes obtained from network providers [11] as well as end user prices found online for the consumer grade APs. These prices however are not exactly what the municipality would pay manufacturers, equipment matures and resource prices fluctuate, which brings forth pricing as an additional cause for uncertainty.

A final set of uncertainties that are introduced are parameters influencing operations and primarily the cost of personnel. Examples are the amount of yearly calls to the helpdesk per user, the average duration of such a call, wages, etc...

To support the conclusion that crowdsourcing significantly reduces TCO the probability distribution of the percentage difference between the traditional and crowdsourced approach is used. Figure 4 captures this function. It focusses on the

Fig. 4. Probability functions for TCO difference between PPP and VNO CWN approaches

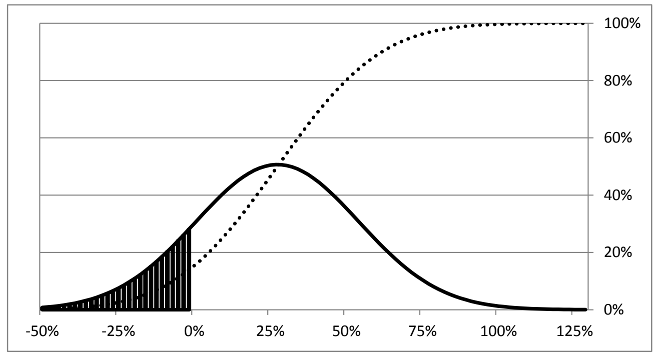
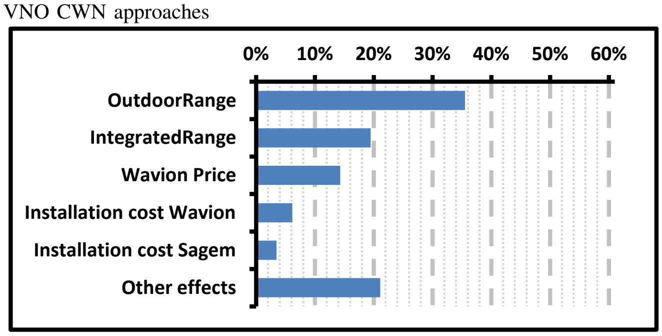


Fig. 5. First order sensitivity indices for TCO difference between PPP and VNO CWN approaches



VNO CWN case which was the least convincing in the static analysis of both crowdsourced approaches and shows that in the 85% percent of the simulations the traditional PPP was indeed outperformed by crowdsourcing. This gives a positive outlook on crowdsourcing but still merrits some additional research into the causes of the other 15%. Sensitivity analysis can provide an interesting tool in this research setting.

The analysis uses variance based sensitivity measures [16] and is captured in figure 5. It lists the first order sensitivity indices, normalized to 1, of the 5 most important determinants of uncertainty of TCO, the higher the index the more critical the assumption. It can be seen as an indicator for prioritizating research, it shows for which variables the input uncertainty reduction that follows research would lead to the biggest reduction in model uncertainty. Or in other words which factors the investor has to put controlling effort into.

If one looks at these charts one can see the importance of an accurate dimensioning of the BSs as well as an accurate prediction of equipment and installation costs as these factors are essential in tipping the scale either in favour of the crowdsourced or the traditional PPP approach. [17] explains a measurement tool that allows accurate dimensioning and reduce uncertainty with respect to the amount of access points. The uncertainty about the costs can be diminished once the municipality starts negotiating with equipment vendors.

VII. Discussion and conclusion

This paper analyzes the applicability of crowdsourcing for a municipal Wi-Fi deployment and focuses on cost effectiveness. This however is not the sole determinant of feasibility. The project should also abide to regulation and terms of use, find financing and even more importantly so, incentivise participants.

Regulation and terms of use were only treated briefly but pointed towards the usability of the VNO CWN model. The topic of finding participants was treated in previous related work [18]. A user survey in Ghent showed that 1 in 2 people are willing to open up their domestic broadband connection where only 1 in 5 is needed for full coverage. Extrapolating this based on population density learns us that in Brussel a participatin ratio of 1 in 7 would be needed and in Paris only 1 in 20, safe margins. [18] further reasearched possible sources for financing and shows that the network can be financed with a average yearly revenue per user (ARPU) of EUR 10, an increase in the tourism tax of EUR 0.30 per night or 1.5% of the tourism sector's marketing budget, obtainable figures again.

Returning to the topic of cost-effectiveness, the paper shows that the crowdsourcing approach can significantly reduce the network's TCO; up to 50%. The prime reason for this conclusion is found to be the difference in equipment cost per square kilometer of the covered area compared to a deployment by a traditional PPP.

The robustness of the results for the VNO CWN approach is tested using uncertainty and sensitivity analysis and deemed to be convincing. The sensitivity analysis further underlines the importance of component cost assesment and accurate network dimensioning. Overall, the conclusion can be made that it is preferable for municipalities and researchers alike to look further into the legal and other institutional aspects of crowdsourced Wi-Fi considering that from a financial perspective there is a distinct possibility for a beneficial case.

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